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Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

03300017.5

FR030056

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R C van Dijk

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
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If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

METHOD FOR VERIFYING THE IDENTITY OF AN OBJECT

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DESCRIPTION

Field of the invention

The invention relates to a verification method for verifying the identity of an object from a verification measurement attached to said object and a pre-stored enrollment measurement.

The invention also relates to an identification device having verification means for verifying the identity of the person who is using said identification device from an enrollment measurement stored in the identification device and a verification measurement attached to said person.

The invention also relates to a reading/writing device for reading/writing data from/onto a record medium, said reading/writing device having verification means for verifying the identity of the record medium that is read/written by said reading/writing device from an enrollment measurement and a verification measurement attached to said record medium.

The invention applies to objects that can be uniquely identified by at least one of their physical characteristics. The object which identity is to be verified may be a device (for instance a storage medium) or a human being. For a storage medium, the physical characteristic to be measured could be the shape of the track of the storage medium. For a human being, the physical characteristic to be measured is usually referred to as biometrics. For instance the biometric to measure could be the fingerprint, a facial feature...

Background of the invention

The report "Smart cards & Biometrics - Forget about PINs" by Dr Norbert Pohlmann published in Business Briefing : Global Infosecurity 2002 describes a system in which a biometric template of an authorized user is deposited on a smart card. A person who claims to be the authorized user of the smart card has to present his biometric. The presented biometric is received by the smart card and compared with the template biometric stored on the card.

In such systems, during a first phase usually referred to as enrollment phase one object is measured. The measurement referred to as enrollment measurement is stored for future reference. During a second phase usually referred to as verification phase, a measurement referred to as verification measurement is made from an object that could be the same object or a different object. Then the enrollment and the verification measurements are compared in order to decide whether or not they originate from the same object.

In this situation, there is no database available for storing the enrollment measurements for all objects. This means that all the measurements that are different from the one to be matched against are completely unknown.

One of the objects of the present invention is to propose a verification method well adapted to such situations.

Another object of the invention is to propose an identification device in which such a verification method is implemented.

Another object of the invention is to propose a device for reading/writing data from/onto a record medium wherein such a verification method is implemented.

Summary of the invention

These objects are achieved with a verification method as defined in claims 1 to 3, an identification device as defined in claims 4 to 6, and a reading/writing device as defined in claims 8 or 9.

According to the invention, the enrollment and the verification measurements are modeled as a first and a second realization of a first random variable affected by an enrollment noise and a verification noise respectively, said enrollment noise being a realization of a second random variable, said verification noise being a realization of a third random variable, said first, second and third random variables having known distributions.

This choice is based on the recognition that:

- in the situations where there is no a priori knowledge on the measurements performed, a measurement attached to an object is a specific realization of a random variable;
- in practice the measurements are always affected by noise both during the enrollment phase and during the verification phase.

This means that the enrollment measurement x_e and the verification measurement x_v are written:

$x_e=s_k+n_e$

$x_v=s_q+n_v$

where:

- s_k and s_q are realizations of a random variable S,
- n_e is the enrollment noise affecting the realization s_k,
- and n_v is the verification noise affecting the realization s_q.

(in the whole text capital letters are used when referred to variables and small letters are used when referred to specific values taken by a variable).

This model being set, the decision to be taken is whether s_k and s_q are the same realizations of the random variable S.

According to the invention, this is achieved by:

- calculating, for the enrollment measurement x_e and the verification measurement x_v, the value of a function g of the ratio $\Lambda(X_e, X_v)$ between of the joint probability density function of two variables X_e and X_v under a first hypothesis where said first and second realizations of the first random variable are the same ($f_1(X_e, X_v)$) and under a second hypothesis where said first and second realizations are different ($f_0(X_e, X_v)$),
- taking a decision whether or not the enrollment measurement x_e and the verification measurement x_v are from the same object by comparing the calculated value $g[\Lambda(x_e, x_v)]$ to a threshold.

Advantageously the function g is a logarithmic function.

It is to be noted that in certain situations the enrollment noise may be reduced by doing multiple measurements in the enrollment phase. There are however situations in which doing multiple enrollment measurements is not possible. And when multiple enrollment measurements are done a certain inaccuracy always remains. Therefore, in all cases, taking into account the enrollment noise allows significant improvement of the performances of the verification process.

Brief description of the drawings

These and other aspects of the invention will be further described with reference to the following drawings:

- figure 1 is a schematic diagram illustrating a model used in a verification method according to the invention,
- figure 2 is a block diagram describing the main steps of a verification method according to the invention,
- figures 3 and 4 illustrate the performances of a verification method according to the invention,
- figure 5 is a schematic representation of a system comprising an example of identification device according to the invention and a reader for reading such an identification device,
- figure 6 is a schematic representation of a system comprising an example of reading/writing device according to the invention and a record medium which identity is to be verified by said reading/writing device.

Description of preferred embodiment

The present invention applies to the verification of the identity of an object based on measurements of at least one physical characteristic of said object. Such a verification process is usually described by referring to two phases: an enrollment phase and a verification phase. In the enrollment phase, an object with known identity is measured. Such measurement referred to as enrollment measurement is stored for future reference. In the verification phase, an object is presented for verification. A measurement of the presented object is made which is referred to as verification measurement. The verification measurement is then compared with the enrollment measurement to decide whether or not the two measurements originate from the same object.

The word "object" in the description and in the claims refers to either devices or living beings.

According to the invention:

- a physical characteristic used to identify an object is modeled as the realization of a random variable S distributed according to a known distribution P_S;
- both the enrollment and the verification measurements of a physical characteristic of an object are supposed to be noisy;

- the enrollment noise is modeled as a realization n_e of a random variable N_e having a known distribution P_{Ne}; and the verification noise n_v is modeled as a realization of a random variable N_v having a known distribution P_{Nv};
- S, N_e and N_v are assumed to be independent random variables.

This model is represented schematically in figure 1. In figure 1, an object k is measured in the enrollment phase and an object q is measured in the verification phase. The enrollment measurement x_e and the verification measurement x_v are written:

$x_e=s_k+n_e$

$x_v=s_q+n_v$

A verifier VB is in charge of deciding whether s_k and s_q are the same realizations of the random variable S based on the enrollment measurement x_e and the verification measurement x_v.

This can be formulated as a decision between two hypotheses: an hypothesis H_0 in which the objects k and q are different and an hypothesis H_1 in which the objects k and q are the same.

Deciding between these two hypotheses can be done by:

- calculating the value of the likelihood ratio $\Lambda(X_e,X_v)=\dfrac{f_1(X_e,X_v)}{f_0(X_e,X_v)}$ for the $X_e=x_e$ and $X_v=x_v$

where:

$f_1(X_e,X_v)$ is the joint probability density function for the variables X_e and X_v under hypothesis H_1, that is when s_k and s_q are the same realization of the random variable S,

$f_0(X_e,X_v)$ is the joint probability density function for the variables X_e and X_v under hypothesis H_0, that is when s_k and s_q are different realizations of the random variable S;

- taking a decision whether or not the enrollment measurement x_e and the verification measurement x_v are from the same object by comparing the calculated value $\Lambda(x_e,x_v)$ to a threshold.

Alternatively, any monotonous function g of the likelihood ratio Λ can be used as a decision function d instead of the likelihood ratio itself.

Figure 2 is a block diagram describing the steps of a verification method according to the invention. At step Z1 a verification measurement x_v is made on an object q. At step Z2, the value $d(x_e,x_v)$ of the decision function d is computed for the verification measurement x_v made at step Z1 and an enrollment measurement x_e. At step Z3, the computed value $d(x_e,x_v)$ is compared to a threshold T:

- if $d(x_e,x_v)<T$ then hypothesis H_0 is chosen
- if $d(x_e,x_v)\geq T$ then hypothesis H_1 is chosen.

At step Z4, the decision (hypothesis H_0 or hypothesis H_1) is output.

A preferred decision function d to be used at step Z3 will now be derived by way of example in the case where all signals are vectors of independent Gaussian distributed random variables. This preferred decision function is the logarithm of the likelihood ratio. As will be apparent from the following, taking the logarithm of the likelihood ratio as a decision function is advantageous because it simplifies the calculations. It is to be understood that this preferred example is not restrictive and that the invention applies to any other monotonous function g of the likelihood ratio and to other forms of distributions.

The logarithm of the likelihood ratio will first be derived for Gaussian distributed scalars, and then for vectors of independent identically and Gaussian distributed scalars.

Logarithm of the likelihood ratio for Gaussian distributed scalars

It is assumed that verifier VB has full knowledge of all the distributions:

- P_S is a known Gaussian distribution with mean μ_s and variance σ_s^2
- P_{Ne} is a known Gaussian distribution with mean μ_{ne} and variance σ_{ne}^2
- P_{Nv} is a known Gaussian distribution with mean μ_{nv} and variance σ_{nv}^2

Generally speaking the bivariate Gaussian probability density function under hypothesis H_j is in the form :

$$f_j(X_e,X_v)=\frac{1}{2\pi\sigma_{xe}\sigma_{xv}\sqrt{1-\rho_j^2}}\times\exp\left[-\frac{\sigma_{xv}^2(X_e-\mu_{xe})^2-2\rho_j\sigma_{xe}\sigma_{xv}(X_e-\mu_{xe})(X_v-\mu_{xv})+\sigma_{xe}^2(X_v-\mu_{xv})^2}{2\sigma_{xe}^2\sigma_{xv}^2(1-\rho_j^2)}\right] \quad \textbf{(1)}$$

In the considered situation:

$$\mu_{xe}=\mu_s+\mu_{ne} \text{ and } \sigma_{xe}=\sqrt{\sigma_s^2+\sigma_{ne}^2}$$

$$\mu_{xv}=\mu_s+\mu_{nv} \text{ and } \sigma_{xv}=\sqrt{\sigma_s^2+\sigma_{nv}^2}$$

In order to simplify the calculations two new variables are introduced:

$$\tilde{X}_e=\frac{X_e-\mu_s-\mu_{ne}}{\sqrt{\sigma_s^2+\sigma_{ne}^2}}$$

$$\tilde{X}_v=\frac{X_v-\mu_s-\mu_{nv}}{\sqrt{\sigma_s^2+\sigma_v^2}}$$

The bivariate Gaussian probability density function under hypothesis H_j for these variables is in the form:

$$f_j(\tilde{X}_e,\tilde{X}_v)=\frac{1}{2\pi\sqrt{1-\rho_j^2}}\times\exp\left[-\frac{\tilde{X}_e^2-2\rho_j\tilde{X}_e\tilde{X}_v+\tilde{X}_v^2}{2(1-\rho_j^2)}\right] \tag{2}$$

In hypothesis H_0, s_k and s_q are independently drawn from the random variable S which means that $\tilde{X}_e$ and $\tilde{X}_v$ are also independent and that $\rho_0=0$. The probability density function f_0 is hence given by:

$$f_0(\tilde{X}_e,\tilde{X}_v)=\frac{1}{2\pi}\times\exp\left[-\frac{\tilde{X}_e^2+\tilde{X}_v^2}{2}\right] \tag{3}$$

In hypothesis H_1, $\tilde{X}_e$ and $\tilde{X}_v$ are correlated and the correlation coefficient ρ_1 is written:

$$\rho_1=\rho=\frac{\sigma_s^2}{\sqrt{\sigma_s^2+\sigma_{ne}^2}\sqrt{\sigma_s^2+\sigma_{nv}^2}}$$

The probability density function f_1 is hence given by:

$$f_1(\tilde{X}_e,\tilde{X}_v)=\frac{1}{2\pi.\sqrt{1-\rho^2}}\times\exp\left[-\frac{\tilde{X}_e^2-2\rho.\tilde{X}_e.\tilde{X}_v+\tilde{X}_v^2}{2(1-\rho^2)}\right] \tag{4}$$

Using (3) and (4) the likelihood ratio can be written as follows:

$$\Lambda(\tilde{X}_e,\tilde{X}_v)=\frac{(1/\sqrt{1-\rho^2})\exp\left[-(\tilde{X}_e^2-2\rho\tilde{X}_e\tilde{X}_v+\tilde{X}_v^2)/2(1-\rho^2)\right]}{\exp\left[-(\tilde{X}_e^2+\tilde{X}_v^2)/2\right]}$$

and the logarithm of the likelihood ratio can be written as follows:

$$\ln\Lambda(\tilde{X}_e,\tilde{X}_v)=-\frac{1}{2}\ln(1-\rho^2)-\frac{\tilde{X}_e^2-2\rho\tilde{X}_e\tilde{X}_v+\tilde{X}_v^2}{2(1-\rho^2)}+\frac{\tilde{X}_e^2+\tilde{X}_v^2}{2}$$

$$\Rightarrow\ln\Lambda(\tilde{X}_e,\tilde{X}_v)=-\frac{1}{2}\ln(1-\rho^2)-\frac{\rho^2(\tilde{X}_e-\tilde{X}_v)^2}{2(1-\rho^2)}+\frac{\rho\tilde{X}_e\tilde{X}_v}{1+\rho} \tag{5}$$

Logarithm of the likelihood ratio for vectors of identically Gaussian distributed scalars

In practice the signals $\mathbf{s}_k$, $\mathbf{s}_q$, $\mathbf{n}_e$ and $\mathbf{n}_v$ can be modeled as vectors of independent identically distributed scalars, which means that:

$\mathbf{s}_k=[s_{k,1}, s_{k,2}, \ldots, s_{k,m}]$ with $s_{k,i}\in P_S$ for $i=1,\ldots,m$

$\mathbf{s}_q=[s_{q,1}, s_{q,2}, \ldots, s_{q,m}]$ with $s_{q,i}\in P_S$ for $i=1,\ldots,m$

$\mathbf{n}_e=[n_{e,1}, n_{e,2}, \ldots, n_{e,m}]$ with $n_{e,i}\in P_{Ne}$ for $i=1,\ldots,m$

$\mathbf{n}_v=[n_{v,1}, n_{v,2}, \ldots, n_{v,m}]$ with $n_{v,i}\in P_{Nv}$ for $i=1,\ldots,m$

where m is the vector length and bold characters are used to refer to vectors.

The probability density function of independent identically distributed sequences is the product of the probability density for each element of the sequence.

Therefore the logarithm of the likelihood ratio for vectors of Gaussian distributed scalars can be derived from (5) :

$$\ln \Lambda(\tilde{\mathbf{X}}_{\mathbf{e}},\tilde{\mathbf{X}}_{\mathbf{v}}) = \sum_{i=1}^{m}\left\{-\frac{1}{2}\ln(1-\rho^2)-\frac{\rho^2(\tilde{X}_{e,i}-\tilde{X}_{v,i})^2}{2(1-\rho^2)}+\frac{\rho.\tilde{X}_{e,i}.\tilde{X}_{v,i}}{1+\rho}\right\} \quad \textbf{(6)}$$

It can be seen from equation (6) that the proposed decision function is a linear weighted function based on both a correlation term $\left(\tilde{X}_{e,i}.\tilde{X}_{v,i}\right)$ and a squared difference term $\left(\left(\tilde{X}_{e,i}-\tilde{X}_{v,i}\right)^2\right)$.

The signal to noise ratio in the enrollment phase is defined as the ratio of σ_s^2 to σ_{ne}^2 The signal to noise ratio in the verification phase is defined as the ratio of σ_s^2 to σ_{nv}^2. When ρ is close to 0, that is when the signal to noise ratio are low, the correlation term is dominant in equation (6). When ρ is close to 1, that is when the signal to noise ratio are high, the squared difference term is dominant.

The performance of the verifier can be given in terms of the EER (Equal Error Rate) which is the value of FRR (False Rejection Rate; hypothesis H_0 chosen when hypothesis H_1 is true) and FAR (False Acceptance Rate; hypothesis H_1 chosen when hypothesis H_0 is true) if the decision threshold is chosen such that FRR=FAR.

Figure 3 gives the EER obtained as a function of the signal to noise ratio (SNR) when the vector length m=20 with the proposed verifier (curve C1), with a verifier based on a correlation only (curve C2) and with a verifier based on a squared difference term only (curve C3). It is supposed here that the signal to noise ratio is the same in the enrolment phase and in the verification phase that is $SNR=\frac{\sigma_s^2}{\sigma_{ne}^2}=\frac{\sigma_s^2}{\sigma_{nv}^2}$. It can be seen from figure 3 that the performance of the verifier according to the invention is significantly better.

Figure 4 gives the EER as a function of the vector length m when the signal to noise ratio SNR is equal to 0dB. It is clear from figure 3 that, for a signal to noise ratio of 0dB, the performance obtained with the verifier based on the correlation only and with the verifier based on the squared difference only are identical. Curve D1 gives the EER as a function of m for the verifier according to the invention. Curve D2 gives the EER as a function of m for the verifier based either on the correlation or on the squared distance. It can be seen from figure 4 that the improvement achieved with the invention is all the more important that the vector length m is large.

Figure 5 is a schematic representation of a system comprising an identification device 10 and a reader 12 for reading the identification device 10. The identification device represented in figure 5 is a smart card comprising a processor 14 and memory means 16 for storing an

enrollment measurement x_e and a program PG comprising instructions for implementing a verification method according to the invention when said program is executed by the processor 14.

Figure 6 is a schematic representation of an example of reading/writing device according to the invention. The reading/writing device represented in figure 6 is an optical device 20 or reading/writing data from/onto an optical disc 22.

The reading/writing device 20 comprises an optical unit 24 that produces a radiation beam 26 intended for scanning a track printed on the optical disc 22, and a processing unit 28. The processing unit 28 is responsible for the encoding/decoding of the signals that are read/to be written by the optical unit 24 and for controlling the operations of the reading/writing device 20.

The track printed on the disc has the form of a spiral line having a continuous sinusoidal deviation from its average centreline. The track shape is advantageously used as a "fingerprint" of the optical disc 22. For instance the track shape can be described by a series of complex values representative of each harmonic of the track deviation.

For tracking and focussing of the radiation beam 26, the optical unit 24 is controlled by a control signal 30 produced by a servo control unit 32. A measurement of the track shape can be derived from the control signal 30.

According to the invention, the reading/writing device 20 comprises a disc fingerprint calculation unit 40 and a verification unit 42. The disc fingerprint calculation unit 40 receives the control signal 30 generated by the servo control unit 32 and produces a measurement referred to as disc fingerprint. The disc fingerprint calculation unit 40 is used in the verification phase to produce a verification measurement x_v attached to a disc q. In the verification phase, the verification unit 42 receives the verification measurement x_v produced by the disc fingerprint calculation unit 40 and an enrolment measurement x_e. It calculates the value $d(x_e, x_v)$ of the decision function d for x_e and x_v and outputs a decision H_0/H_1. The decision H_0/H_1 is forwarded to the processing unit 28 for subsequent action.

The enrolment measurement x_e may be produced by the disc fingerprint calculation unit 40 during the enrollment phase and stored in a memory of the reading/writing device 20 for future use by the verification unit 42. Alternatively, the enrolment measurement x_e may be provided to the verification unit 42 through an independent input of the reading/writing device 20. For instance it may be stored on the disc during the manufacturing process and read when the disc is inserted in the reading/ writing unit 20.

For verifying the identity of an optical disc by using the spectral components of the track deviation, the distributions used for modelling the random variable S, the enrollment noise and the verification noise are advantageously Gaussian distributions.

With respect to the described verification method, identification unit, and reading/writing device, modifications or improvements may be proposed without departing from the scope of the invention. The invention is thus not limited to the examples provided.

In particular the invention is not restricted to the use of a logarithm function or to the use of Gaussian distributions. The proposed decision function can be used to identify other objects than smart card user or record media. The invention applies to other type of record media than optical discs.

The verification method of the invention may use a single physical characteristic or several physical characteristics at the same time. When several physical characteristics are used, these characteristics are processed as a vector.

In the above description, the logarithm of the likelihood ratio has been derived for vectors of identically distributed scalars. This is not restrictive. The invention also applies when the components of the vectors are drawn from different distributions.

The use of the word "comprise" does not exclude the presence of other elements or steps than those listed.

CLAIMS

1. A verification method for verifying the identity of an object from a verification measurement attached to said object and a pre-stored enrollment measurement,
wherein the enrollment and the verification measurements are modeled as a first and a second realization of a first random variable affected by an enrollment noise and a verification noise respectively, said enrollment noise being a realization of a second random variable, said verification noise being a realization of a third random variable, said first, second and third random variables having known distributions,
said verification method comprising the steps of:
- calculating, for said enrollment measurement and said verification measurement, the value of a function of the ratio between a bivariate joint probability density function under a first hypothesis where said first and second realizations of the first random variable are the same and under a second hypothesis where said first and second realizations are different,
- taking a decision whether or not the enrollment measurement and the verification measurement are from the same object by comparing the calculated value to a threshold.

2. A verification method as claimed in claim 1, wherein said function is a logarithmic function.

3. A verification method as claimed in claim 1, wherein said known distributions are Gaussian distributions.

4. An identification device intended for receiving a verification measurement attached to a user, said identification device comprising storage means for storing an enrollment measurement and verification means for verifying the identity of said user from said verification measurement and said enrollment measurement,
wherein the enrollment and the verification measurements are modeled as a first and a second realization of a first random variable affected by an enrollment noise and a verification noise respectively, said enrollment noise being a realization of a second random variable, said verification noise being a realization of a third random variable, said first, second and third random variables having known distributions,
and said verification means comprise:
- means for calculating, for said enrollment measurement and said verification measurement, the value of a function of the ratio between a bivariate joint probability density function under a first hypothesis where said first and second realizations of the first random variable are the same and under a second hypothesis where said first and second realizations are different,
- means for taking a decision whether or not the enrollment measurement and the verification measurement are from the same object by comparing the calculated value to a threshold.

5. An identification device as claimed in claim 4 wherein said measurements are measurement of a physiological or a behavioural characteristic of said user.

6. An identification device as claimed in claim 4 wherein said known distributions are Gaussian distributions.

7. A smart card comprising an identification device as claimed in one of claims 4 or 5.

8. A reading/writing device for reading and/or writing data from/onto a record medium, said reading/writing device having:
- measurement means for generating a measurement attached to a record medium, said measurement uniquely identifying said record medium,
- verification means for verifying the identity of a record medium from a verification measurement attached to said record medium and an enrollment measurement,
wherein the enrollment and the verification measurements are modeled as a first and a second realization of a first random variable affected by an enrollment noise and a verification noise respectively, said enrollment noise being a realization of a second random variable, said verification noise being a realization of a third random variable, said first, second and third random variables having known distributions,
and said verification means comprise:
- means for calculating, for said enrollment measurement and said verification measurement, the value of a function of the ratio between a bivariate joint probability density function under a first hypothesis where said first and second realizations of the first random variable are the same and under a second hypothesis where said first and second realizations are different,
- decision means for taking a decision whether or not the enrollment measurement and the verification measurement are from the same record medium by comparing the calculated value to a threshold.

9. A reading/writing device as claimed in claim 6 comprising a reading/writing unit and control means for generating a control signal that is intended to control said reading/writing unit, wherein said measurement means comprise processing means for generating a set of values representing the frequency spectrum of said control signal when reading/writing data from/onto a record medium, said set of values constituting the measurement attached to said record medium.

10. A program comprising instructions for implementing verification method as claimed in claim 1 or 2 when said program is executed by a processor.

ABSTRACT

METHOD FOR VERIFYING THE IDENTITY OF AN OBJECT

The invention applies to the verification of the identity of an object based on measurements of a physical characteristic of said object. In an enrollment phase, an object with known identity is measured. The resulting enrollment measurement is stored for future reference. Then in the verification phase, an object presented for verification is measured, and the verification measurement is compared with the enrollment measurement to decide whether or not the two measurements originate from the same object.

According to the invention, the enrollment and the verification measurements are modeled as two realizations of a first random variable affected by an enrollment noise and a verification noise respectively, said enrollment and verification noises being a realization of a second and a third random variable respectively, said first, second and third random variables having known distributions.

Application: smart card, optical drives nc

Reference: figure 1.

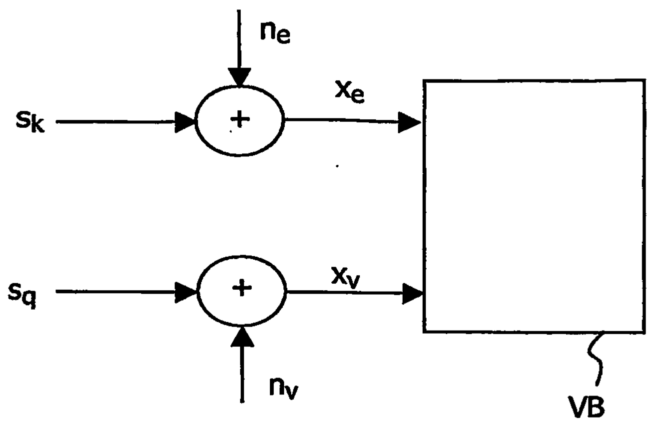
n_e
s_k
+
x_e
s_q
+
x_v
n_v
VB

FIG.1

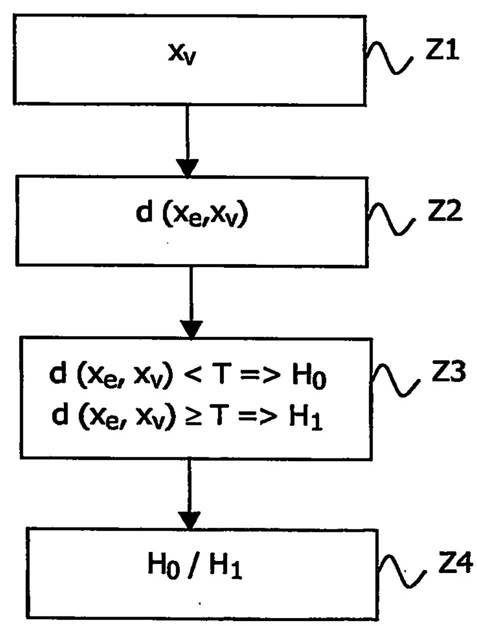
x_v
Z1
$d(x_e,x_v)$
Z2
$d(x_e, x_v) < T \Rightarrow H_0$
$d(x_e, x_v) \geq T \Rightarrow H_1$
Z3
H_0 / H_1
Z4

FIG.2

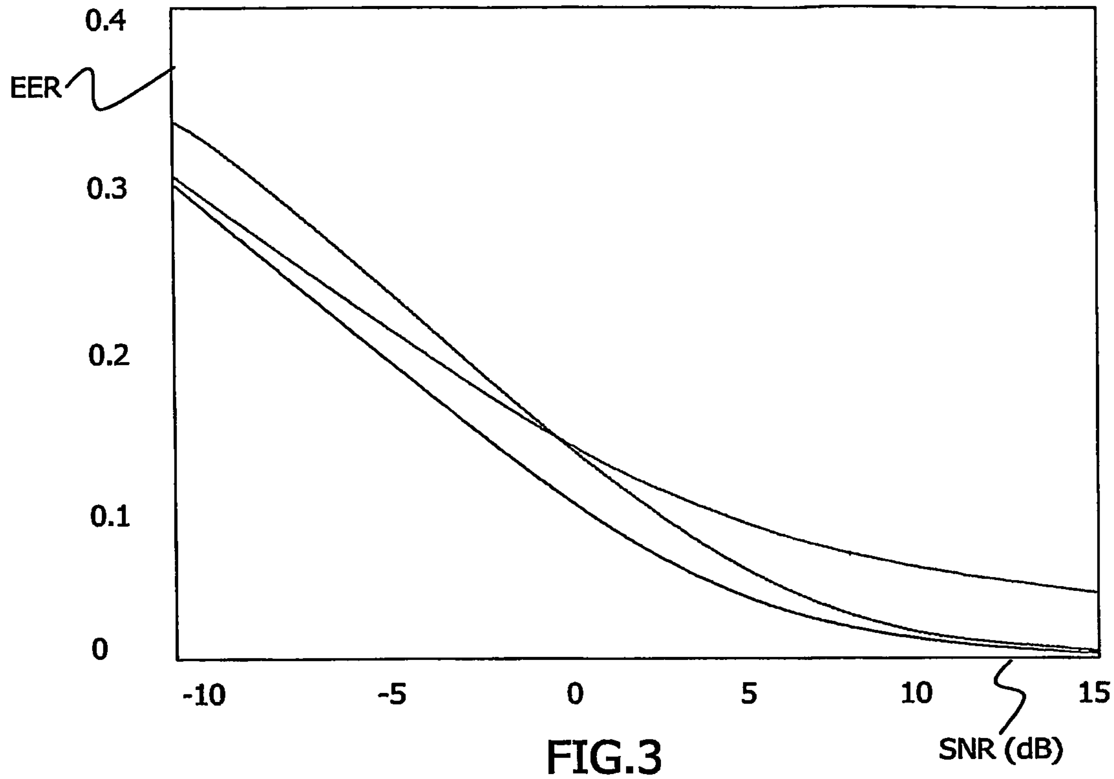
0.4
EER
0.3
0.2
0.1
0
-10
-5
0
5
10
15
SNR (dB)

FIG.3

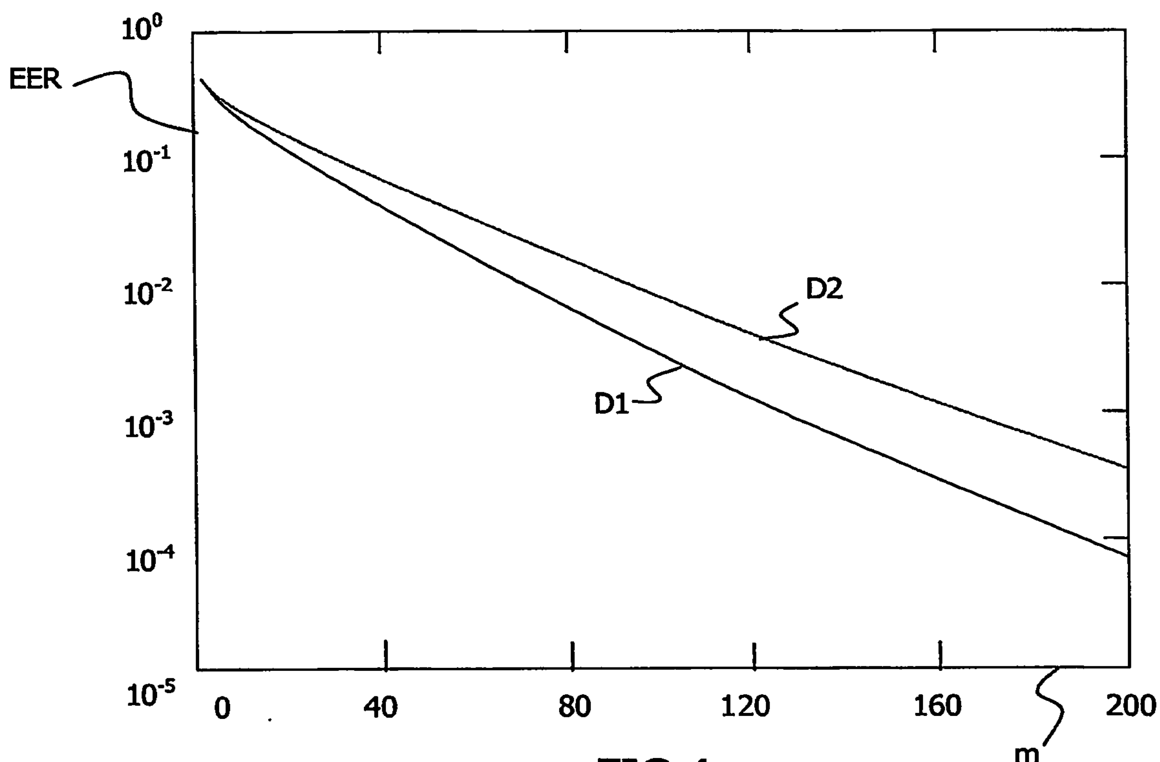
10^0
EER
10^{-1}
10^{-2}
D2
D1
10^{-3}
10^{-4}
10^{-5}
0
40
80
120
160
200
m

FIG.4

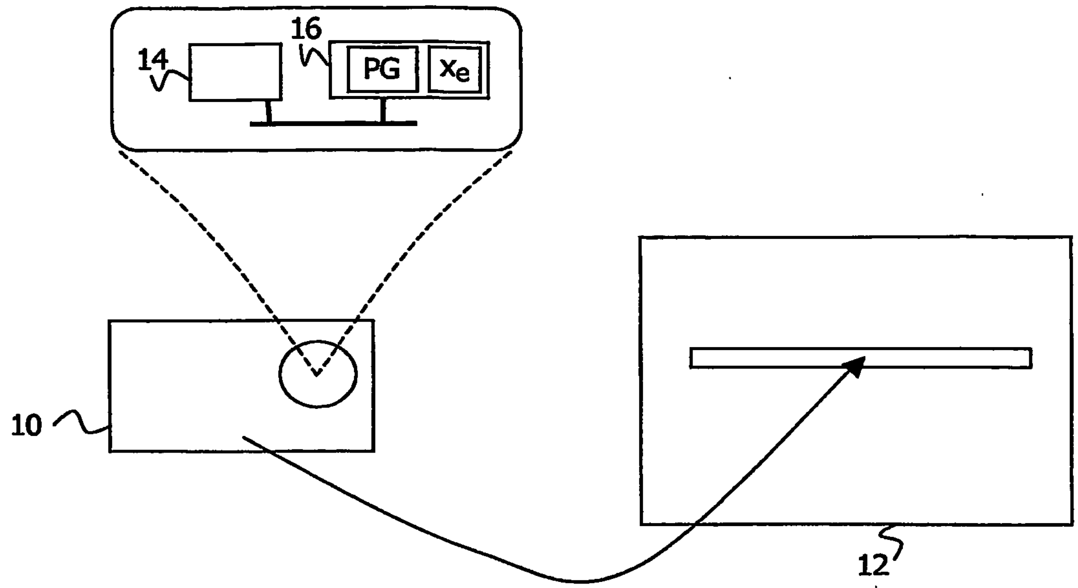

FIG.5

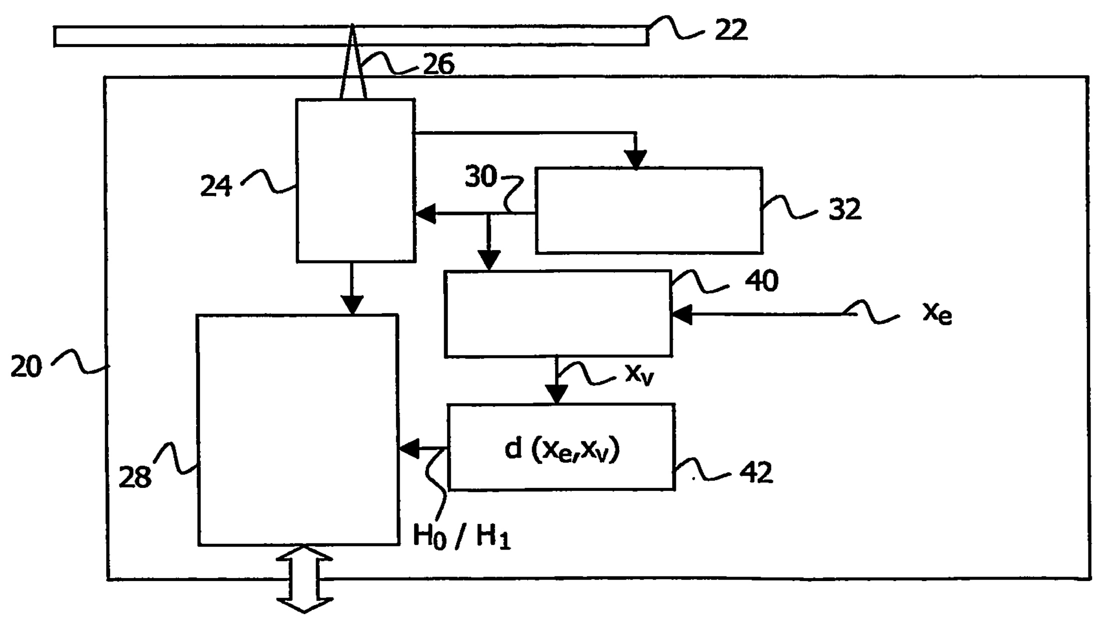

FIG.6

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